Nuclear data measurements
Part I

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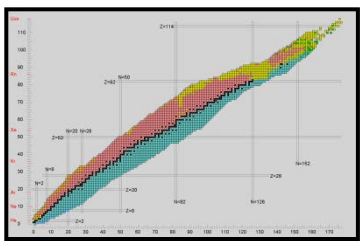
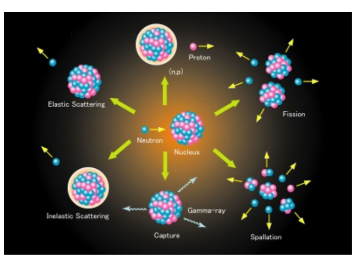
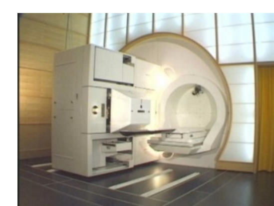
Uppsala University

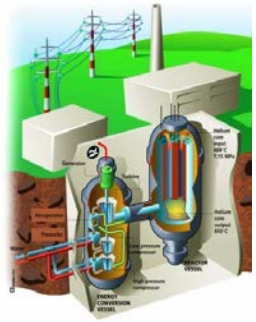




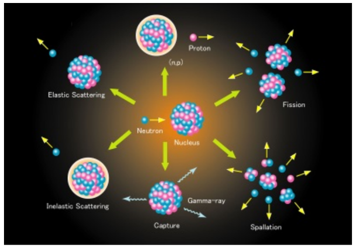


Outline

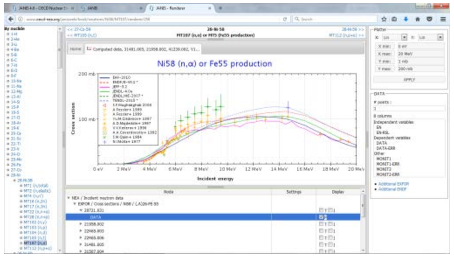
- Nuclear data measurements is about fulfilling needs …



- Which data?



- How to select? And where to start?
  - User needs, HPRL, JANIS, EXFOR …



- An example

Outline

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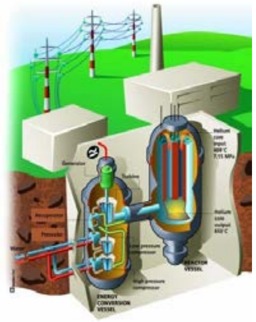

- Which data?
- How to select? And where to start?
  - User needs, HPRL, JANIS, EXFOR …
- An example

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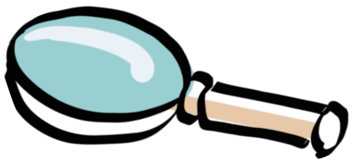
We have a facility now we shall make good use of it …

Beam monitor



Beam

Sample

Detector arrangement

Electronics and DAQ

Analysis

Results

Fulfilling some needs

(the original reason …)

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Nuclear data: what's it about?

Nuclear physics

identify needs

provide data

Applications
(demands and needs from users)

Theoretical:
- Nuclear reaction modelling

Experimental:
- Nuclear physics measurements
- Detection and measurement techniques

Computatior
- Simulation c
- Analysis methods

Nuclear data evaluation methodology

At the core: empirical data

Medical:
- Nuclear medicine, Dosimetry, …
- Drug development, Regenerative medicine, …

Materials:
- Semiconductors, Radiation damage, …

/:
- on (GenIV, fuel cycle,…), Fusion, …

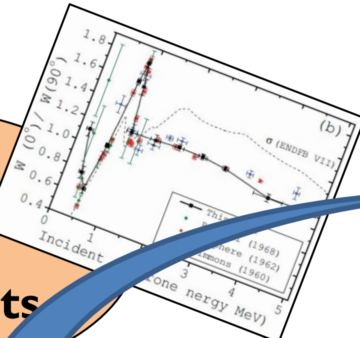
Safety and Security:
- Safeguards, …

Environment:
- Radioecology, …

Science:
- Archaeology, Astrophysics, Geology, …

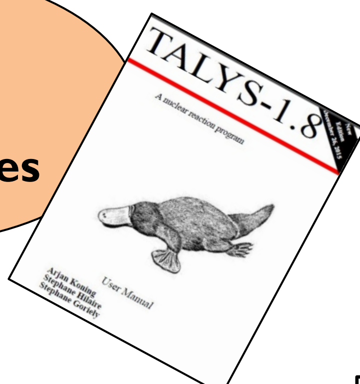
Nuclear data: how is it done?

Requirements
(sensitivity analysis)

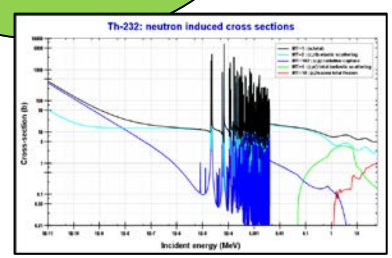


Nuclear physics **experiments**

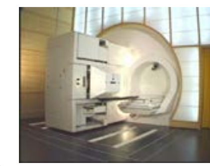
Nuclear physics **model codes**

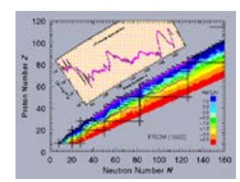


Nuclear data **evaluation**



End-user **applications**





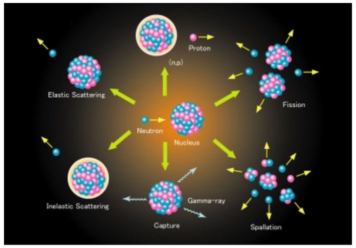
Covariances! QA: Reproducibility, etc.
(see, e.g., the TENDL project)

Koning and Rochman, Nucl. Data Sheets 113 (2012) 2841

Outline

- Nuclear data measurements is about fulfilling needs …

- Which data?

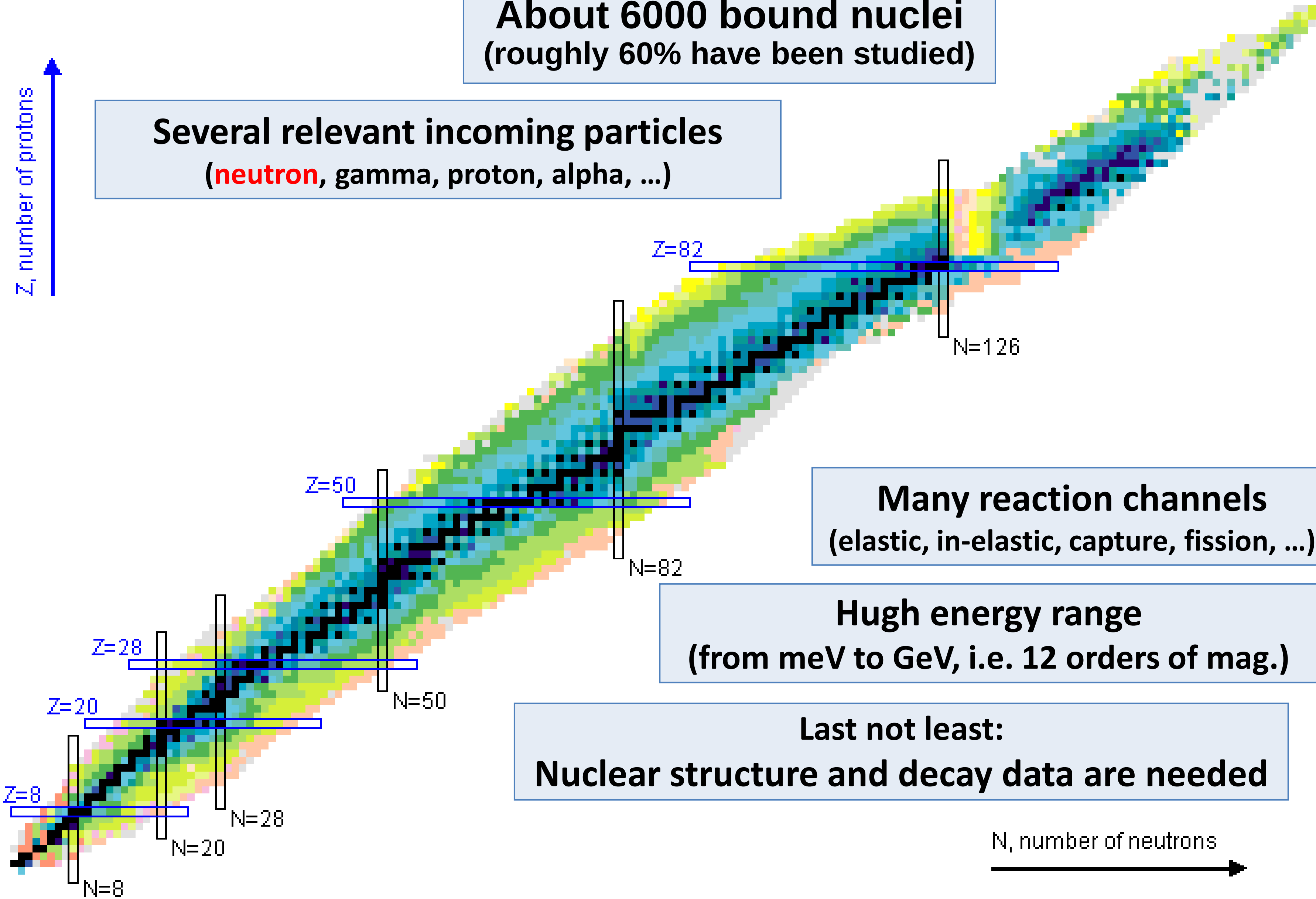


- How to select? And where to start?
  - User needs, HPRL, JANIS, EXFOR …

- An example

About 6000 bound nuclei
(roughly 60% have been studied)

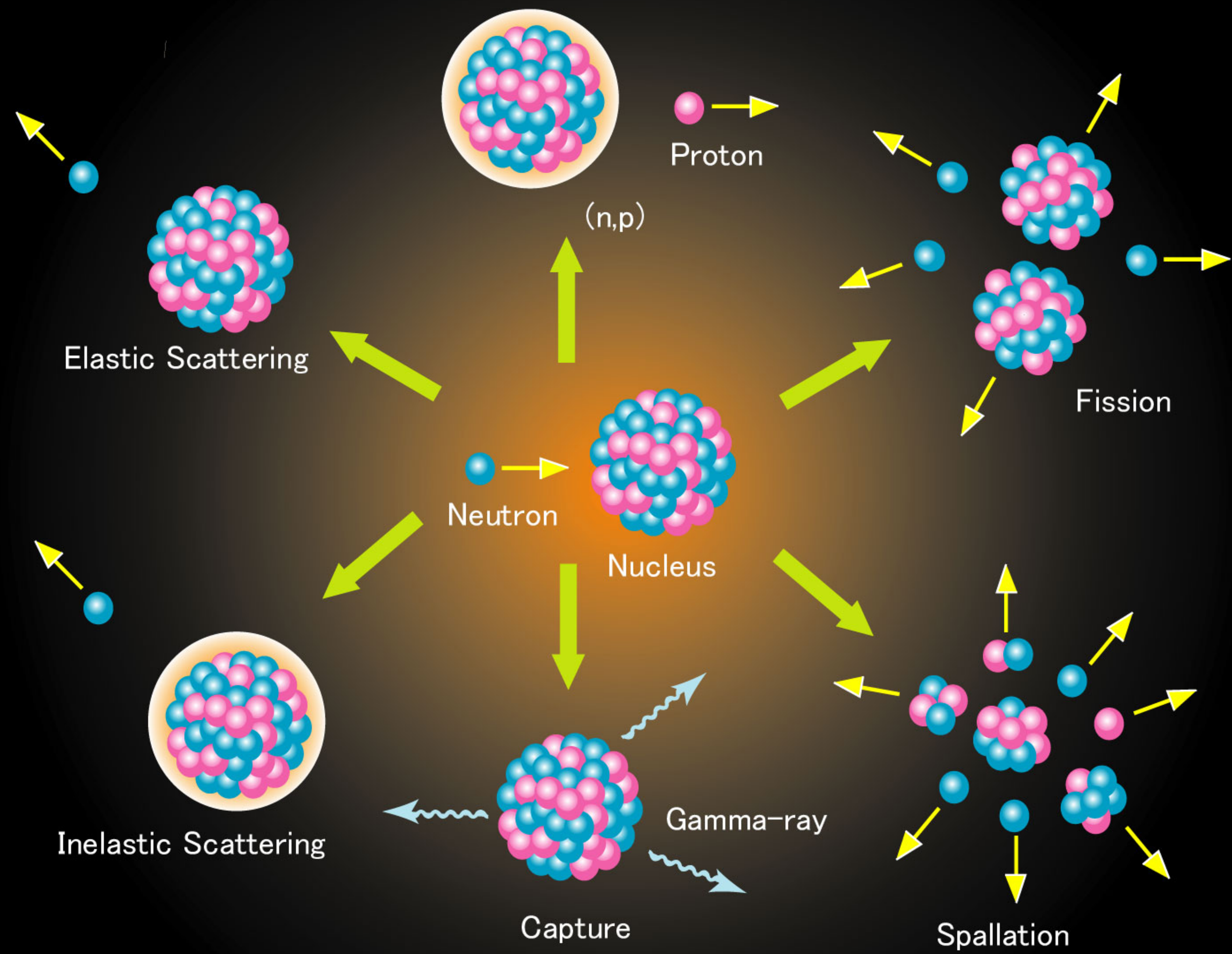
Several relevant incoming particles
(neutron, gamma, proton, alpha, …)

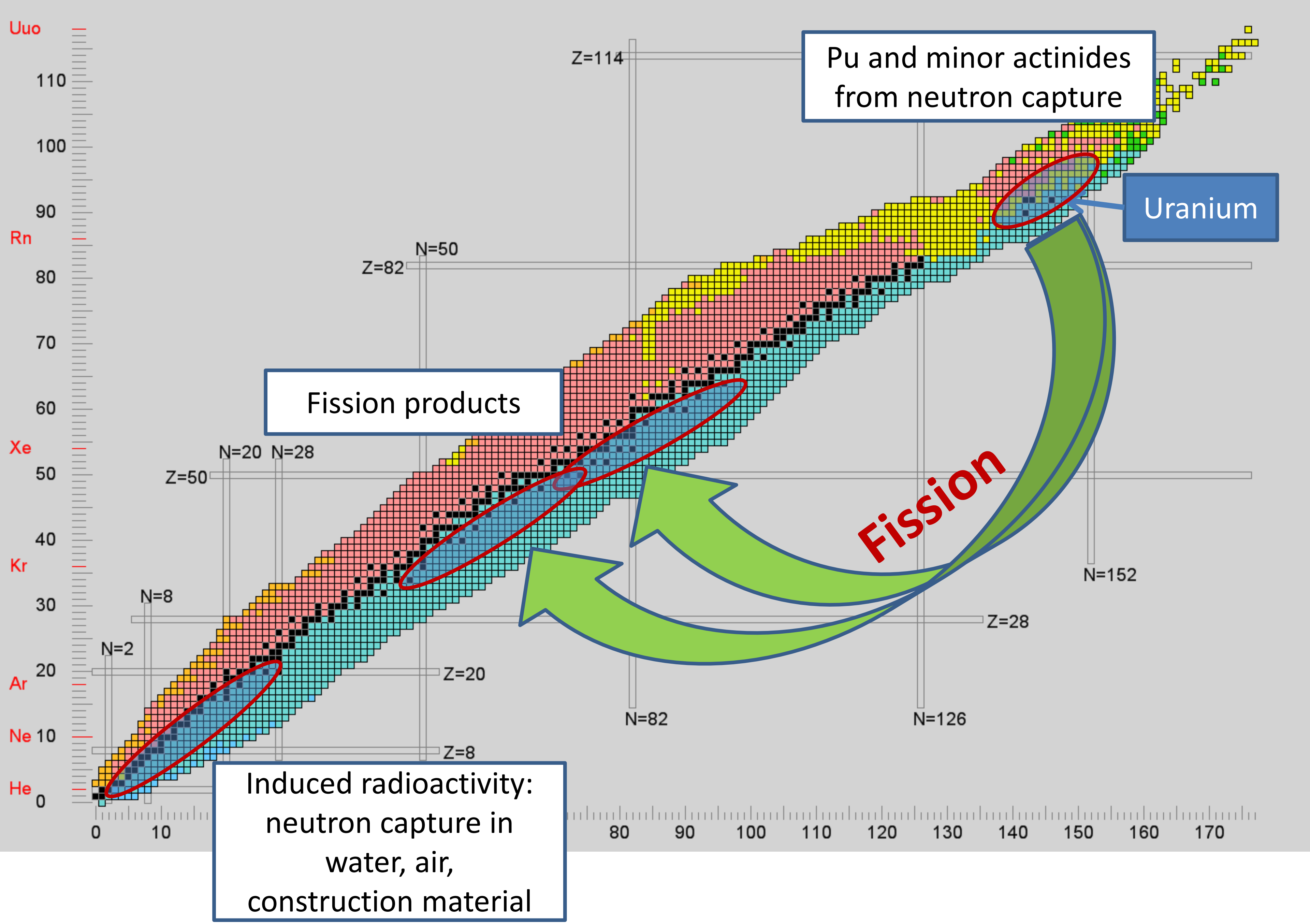


Many reaction channels
(elastic, in-elastic, capture, fission, …)

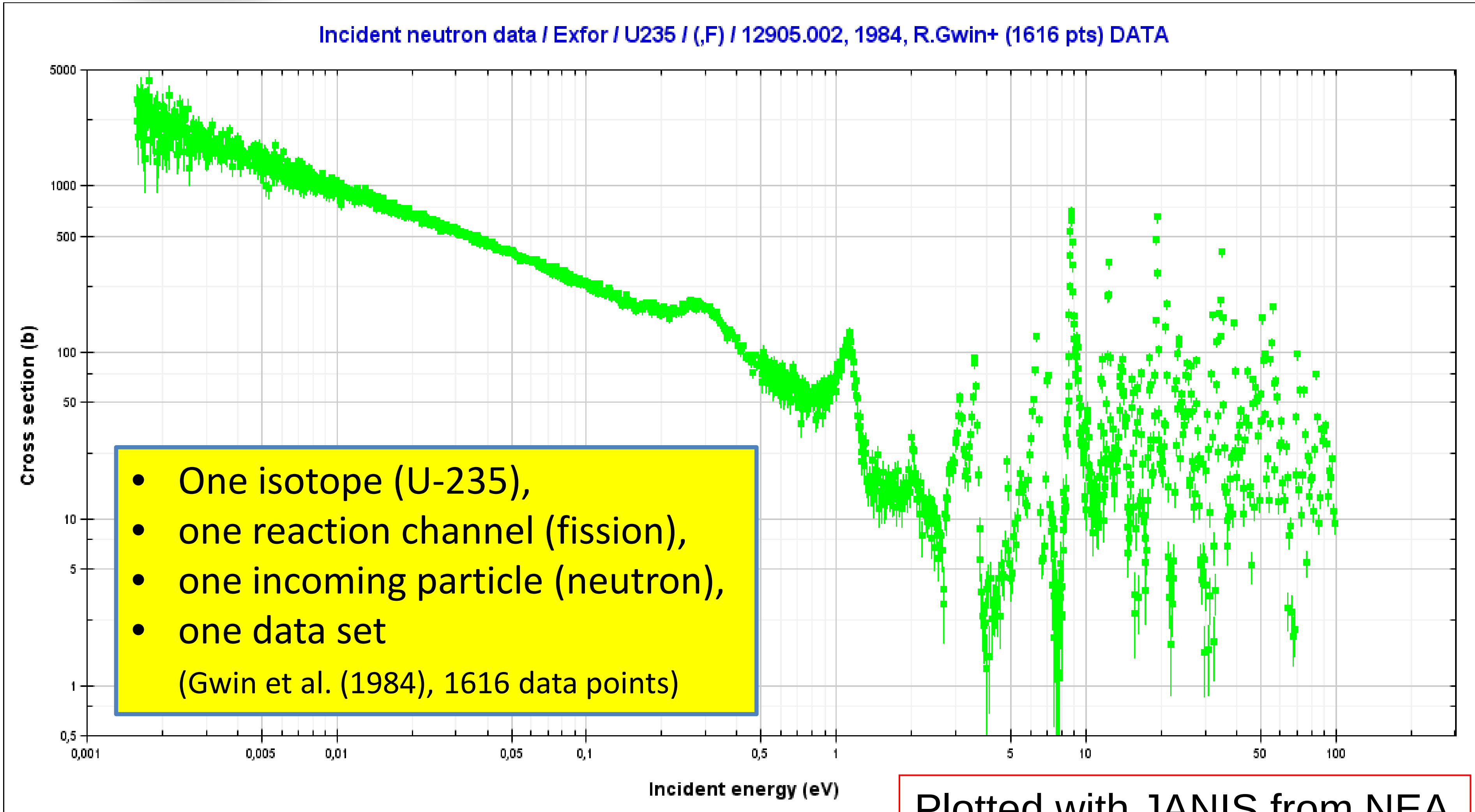
Hugh energy range
(from meV to GeV, i.e. 12 orders of mag.)

Last not least:
Nuclear structure and decay data are needed


Proton
(n,p)
Elastic Scattering
Fission
Neutron
Nucleus
Inelastic Scattering
Gamma-ray
Capture
Spallation


Pu and minor actinides from neutron capture
Uranium
Fission products
Fission
Induced radioactivity: neutron capture in water, air, construction material
Uuo
Rn
Xe
Kr
Ar
Ne
He
Z=114
Z=82
Z=50
Z=28
Z=20
Z=8
N=2
N=8
N=20
N=28
N=50
N=82
N=126
N=152
0
10
20
30
40
50
60
70
80
90
100
110
0
10
80
90
100
110
120
130
140
150
160
170

The truth?
(yes we need models)



- One isotope (U-235),
- one reaction channel (fission),
- one incoming particle (neutron),
- one data set

  (Gwin et al. (1984), 1616 data points)

Plotted with JANIS from NEA

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Physical quantities of interest
(i.e. to be stored in nuclear data files)

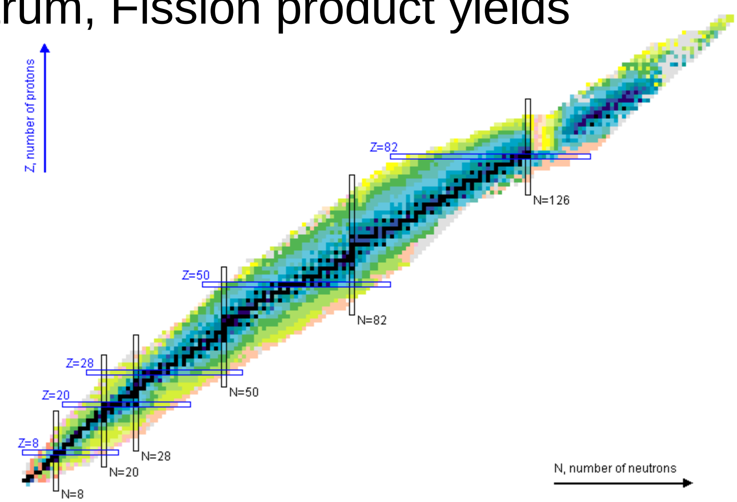
basic

- Cross sections $\sigma(E)$
- Angular distributions (emitted particles) $d\sigma/d\Omega$
- Energy spectra (emitted particles) $d\sigma/dE'$
- Energy-Angle correlated spectra $d^2\sigma/dE'd\Omega$
  (Double-differential cross section, DDX)

practical

- Resonance parameters
- Neutrons per fission, Fission energy spectrum, Fission product yields
- …

- Covariance data



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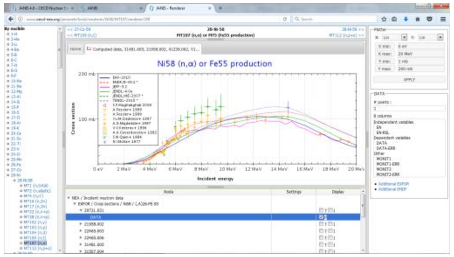

- An example

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E.g.: Needs for fission reactors

- **Fast neutron**
- **Transmutation and target design in ADS**
- **High burn-up systems.**
- **Structural materials and coolants**

Cross sections (fission, capture, scattering)

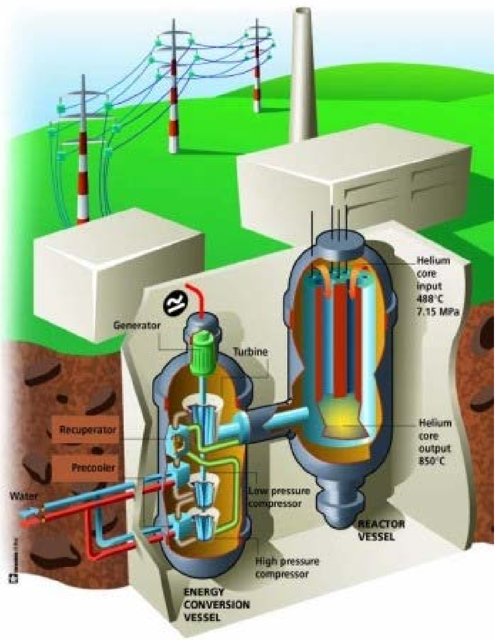
Fission neutron spectra, Nu-bar

Gamma source term, Spent fuel inventories,

Decay heat, and dose rates

A High Priority Request List (Short list) :

- fission cross sections of ^{234}U, ^{237}Np, $^{238,240\text{-}242}$Pu, ^{241,242m,243}Am, $^{242\text{-}246}$Cm
- fission nu-bar of ^{238,240}Pu, ^{241}Am and ^{244}Cm
- capture of ^{235,238}U, ^{237}Np, $^{238\text{-}242}$Pu, ^{241,242m,243}Am, ^{244}Cm
- inelastic scattering of ^{238}U, ^{239,240,242}Pu, ^{241,243}Am, C, O, Na, ^{56}Fe, Pb, Bi, ^{90}Zr
- neutron removal of ^{10}B, C, O, Na, Si, Fe, Ni, Pb
- elastic scattering of ^{238}U, C, ^{15}N, O, ^{52}Cr, ^{56}Fe, Pb



And

- Prompt neutrons and gamma fission spectra
- Delayed neutrons and gamma yield

Need of accurate measurements of neutron induced reactions

Slide courtesy X. Ledoux

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NEA Nuclear Data HPRL

http://www.oecd-nea.org/dbdata/hprl/

Home | About Us | Work Areas | Data Bank | Publications | Delegates

NEA Nuclear Energy Agency

NEA search engine

Nuclear Data Services

NEA Nuclear Data High Priority Request List

HPRL-Main | Search | New request template | New request guidelines | Related references

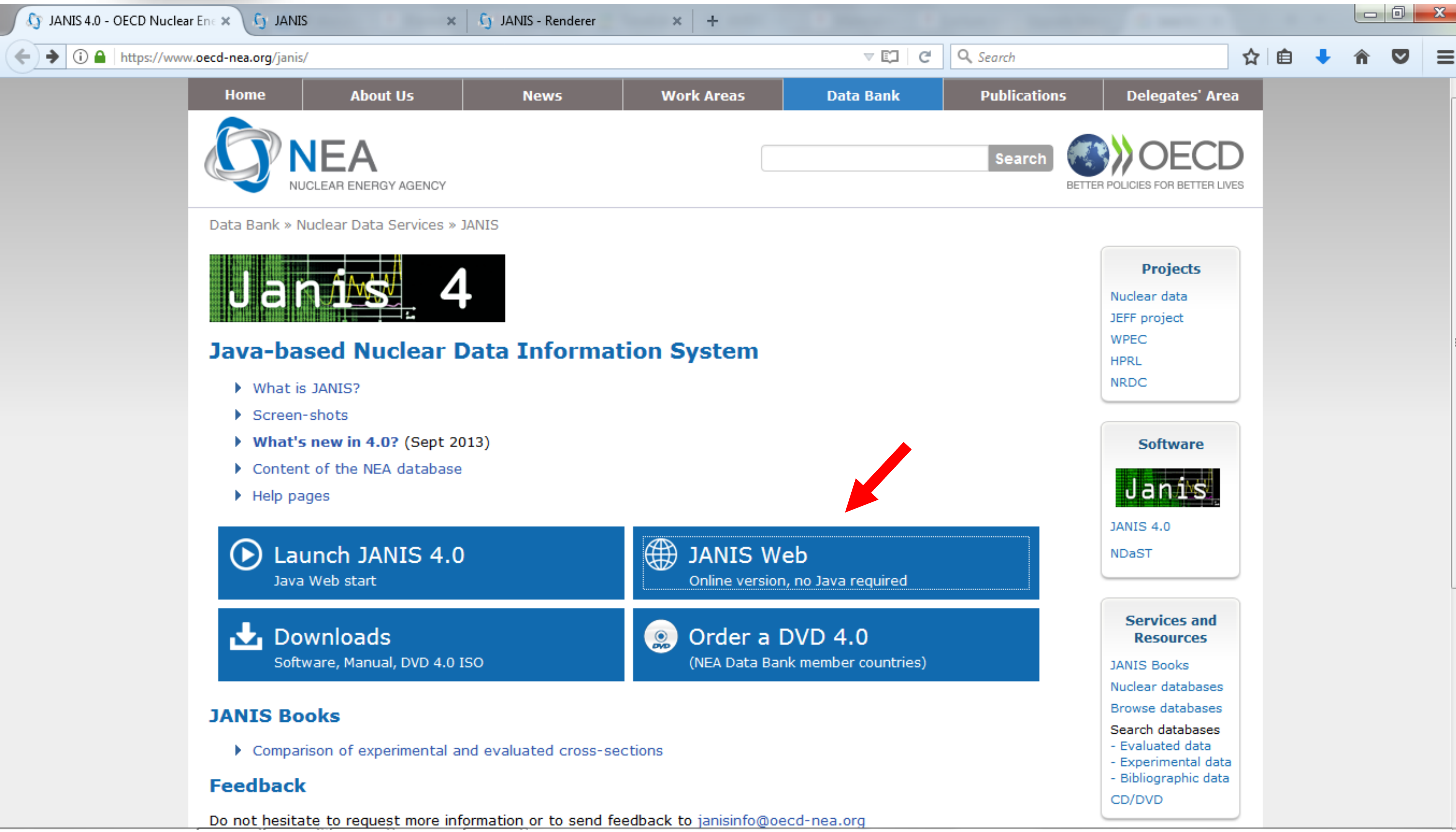
The NEA Nuclear Data High Priority Request List (HPRL), is a compilation of the most important nuclear data requirements. The purpose of the list is to provide a guide for those planning measurement, nuclear theory and evaluation programmes. See also the historical background to the present request list.

The list is maintained by the NEA Working Party on International Nuclear Data Evaluation Cooperation (WPEC).

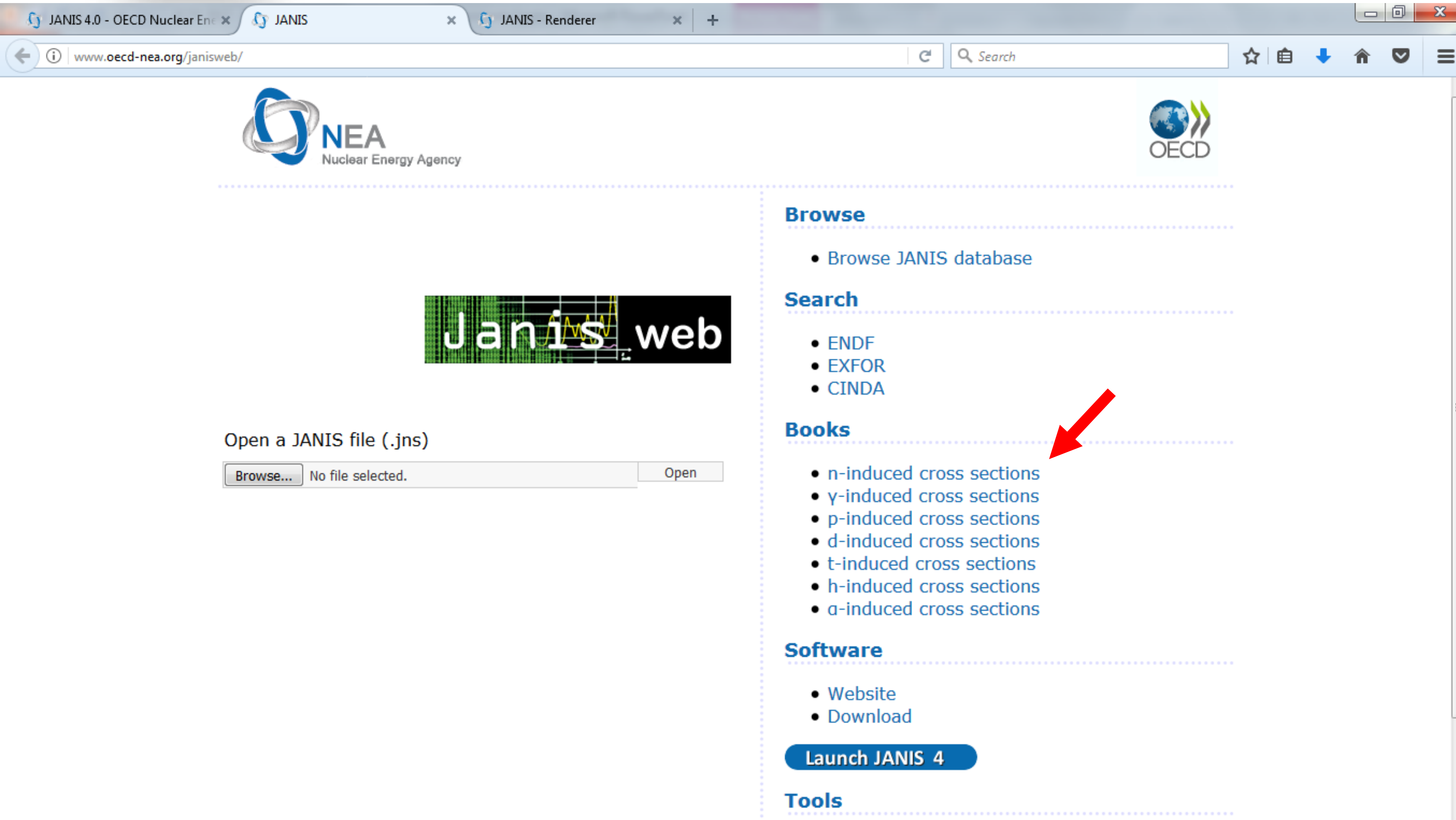
The basic philosophy of the present list is [...] to stimulate nuclear research that will lead to improved quantitative knowledge of important nuclear processes based on requests received from the nuclear science community.

Requests for improved nuclear data may be submitted by any members of the broad nuclear science community who possess knowledge of the data issue that gives rise to the request,
and who can provide the information required to complete the data request submission template.
It is anticipated that most of the requests received by the NEA will be from the data user community,
and that these requests will be associated with specific contemporary nuclear science and technology projects. [...]

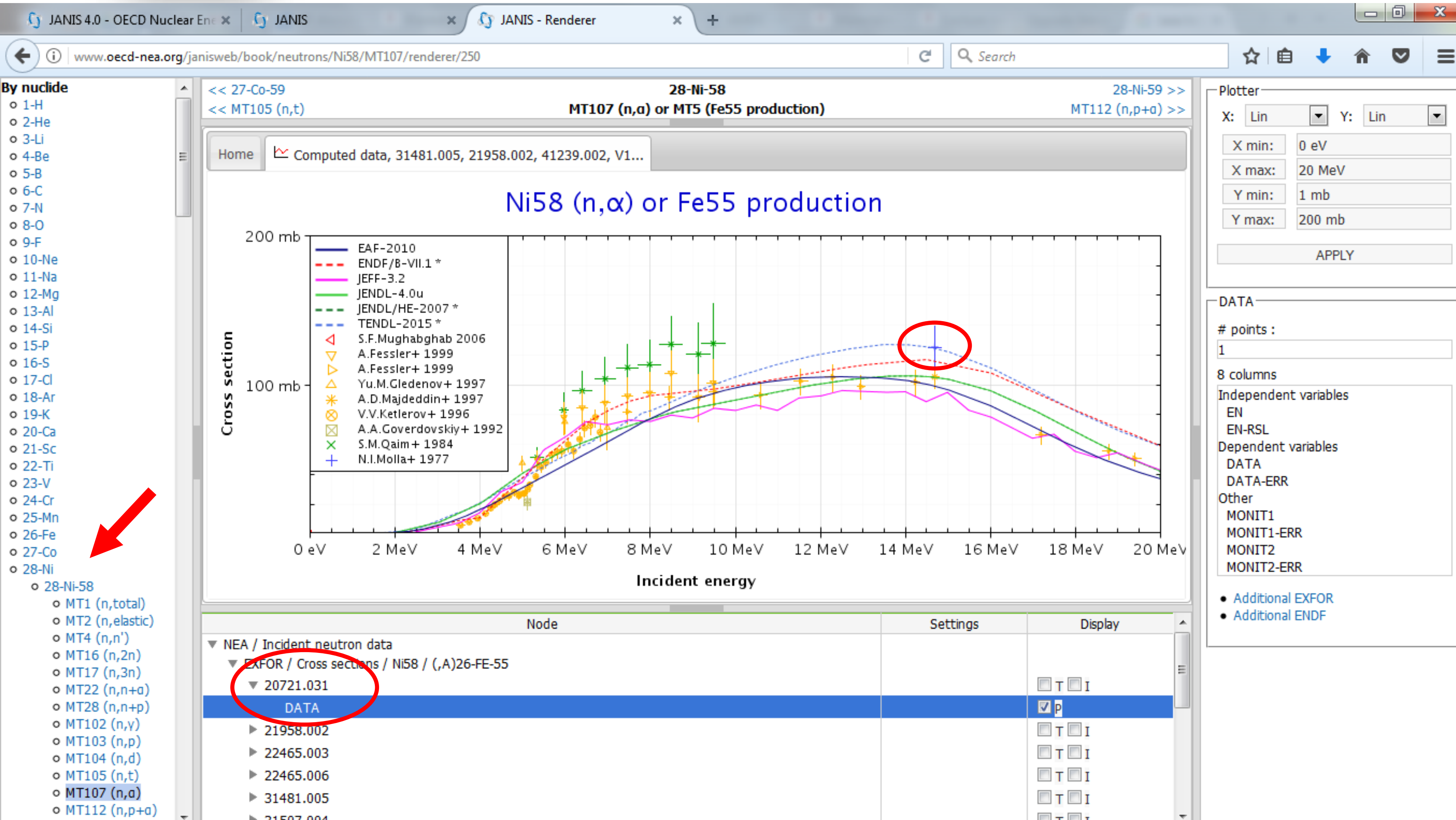
Current knowledge? JANIS …



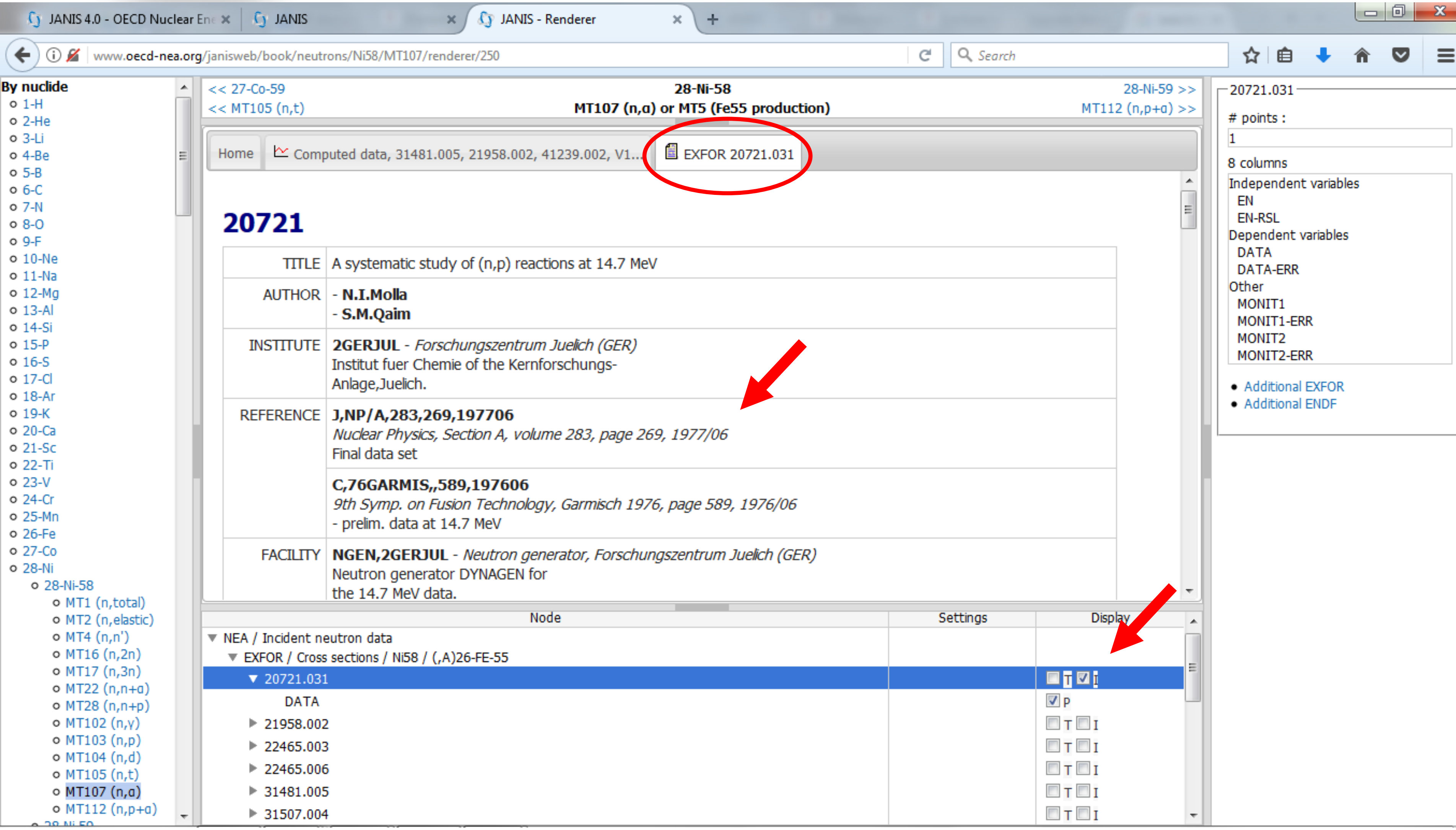
JANIS


JANIS 4.0 - OECD Nuclear En
JANIS
JANIS - Renderer
www.oecd-nea.org/janisweb/
Search
NEA
Nuclear Energy Agency
OECD
Janis web
Open a JANIS file (.jns)
Browse...
No file selected.
Open
Browse
Browse JANIS database
Search
ENDF
EXFOR
CINDA
Books
n-induced cross sections
γ-induced cross sections
p-induced cross sections
d-induced cross sections
t-induced cross sections
h-induced cross sections
α-induced cross sections
Software
Website
Download
Launch JANIS 4
Tools

JANIS


JANIS 4.0 - OECD Nuclear En
JANIS
JANIS - Renderer
www.oecd-nea.org/janisweb/book/neutrons/Ni58/MT107/renderer/250
Search
By nuclide
1-H
2-He
3-Li
4-Be
5-B
6-C
7-N
8-O
9-F
10-Ne
11-Na
12-Mg
13-Al
14-Si
15-P
16-S
17-Cl
18-Ar
19-K
20-Ca
21-Sc
22-Ti
23-V
24-Cr
25-Mn
26-Fe
27-Co
28-Ni
28-Ni-58
MT1 (n,total)
MT2 (n,elastic)
MT4 (n,n')
MT16 (n,2n)
MT17 (n,3n)
MT22 (n,n+α)
MT28 (n,n+p)
MT102 (n,γ)
MT103 (n,p)
MT104 (n,d)
MT105 (n,t)
MT107 (n,α)
MT112 (n,p+α)
<< 27-Co-59
28-Ni-58
28-Ni-59 >>
<< MT105 (n,t)
MT107 (n,α) or MT5 (Fe55 production)
MT112 (n,p+α) >>
Home
Computed data, 31481.005, 21958.002, 41239.002, V1...
Ni58 (n,α) or Fe55 production
200 mb
100 mb
Cross section
EAF-2010
ENDF/B-VII.1 *
JEFF-3.2
JENDL-4.0u
JENDL/HE-2007 *
TENDL-2015 *
S.F.Mughabghab 2006
A.Fessler+ 1999
A.Fessler+ 1999
Yu.M.Gledenov+ 1997
A.D.Majdeddin+ 1997
V.V.Ketlerov+ 1996
A.A.Goverdovskiy+ 1992
S.M.Qaim+ 1984
N.I.Molla+ 1977
0 eV
2 MeV
4 MeV
6 MeV
8 MeV
10 MeV
12 MeV
14 MeV
16 MeV
18 MeV
20 MeV
Incident energy
Node
Settings
Display
NEA / Incident neutron data
EXFOR / Cross sections / Ni58 / (,A)26-FE-55
20721.031
DATA
21958.002
22465.003
22465.006
31481.005
31507.004
Plotter
X: Lin
Y: Lin
X min: 0 eV
X max: 20 MeV
Y min: 1 mb
Y max: 200 mb
APPLY
DATA
points :
1
8 columns
Independent variables
EN
EN-RSL
Dependent variables
DATA
DATA-ERR
Other
MONIT1
MONIT1-ERR
MONIT2
MONIT2-ERR
Additional EXFOR
Additional ENDF

JANIS



JANIS 4.0 - OECD Nuclear En
JANIS
JANIS - Renderer
www.oecd-nea.org/janisweb/book/neutrons/Ni58/MT107/renderer/250
Search
By nuclide
1-H
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28-Ni-58
MT1 (n,total)
MT2 (n,elastic)
MT4 (n,n')
MT16 (n,2n)
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<< 27-Co-59
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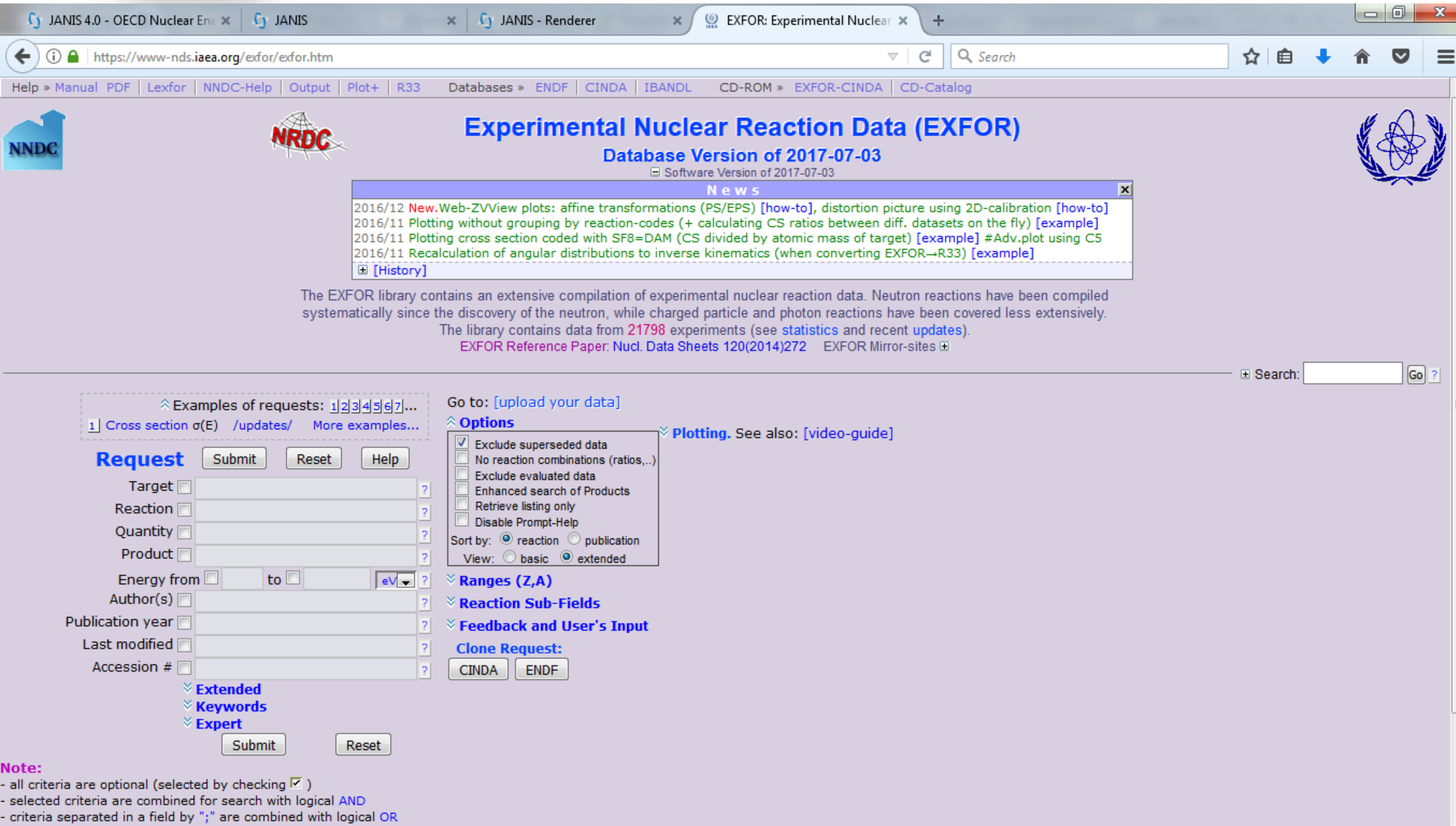
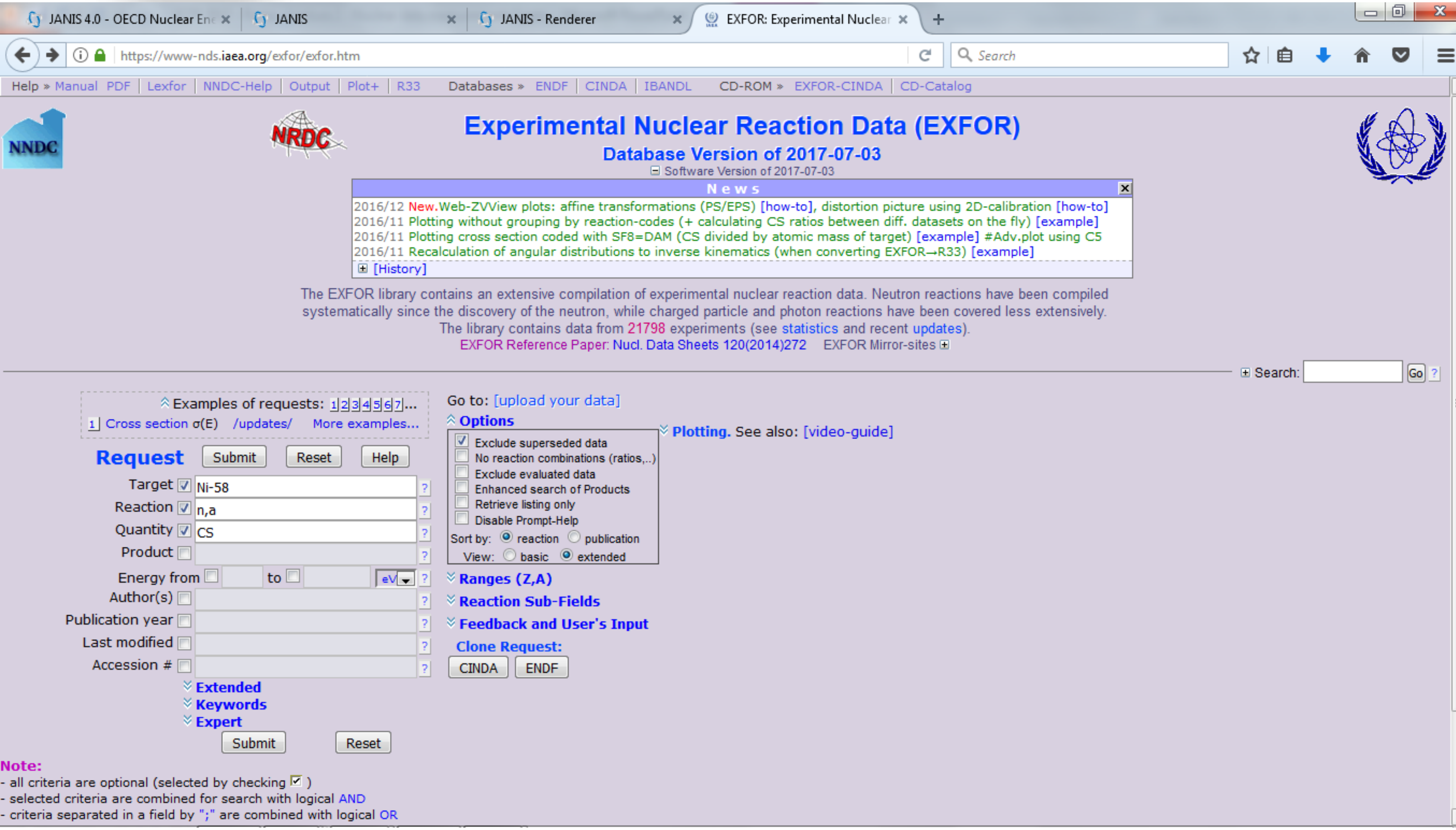
MT107 (n,α) or MT5 (Fe55 production)
MT112 (n,p+α) >>
Home
Computed data, 31481.005, 21958.002, 41239.002, V1...
EXFOR 20721.031
20721
TITLE
A systematic study of (n,p) reactions at 14.7 MeV
AUTHOR
- N.I.Molla
- S.M.Qaim
INSTITUTE
2GERJUL - Forschungszentrum Juelich (GER)
Institut fuer Chemie of the Kernforschungs-
Anlage,Juelich.
REFERENCE
J,NP/A,283,269,197706
Nuclear Physics, Section A, volume 283, page 269, 1977/06
Final data set
C,76GARMIS,,589,197606
9th Symp. on Fusion Technology, Garmisch 1976, page 589, 1976/06
- prelim. data at 14.7 MeV
FACILITY
NGEN,2GERJUL - Neutron generator, Forschungszentrum Juelich (GER)
Neutron generator DYNAGEN for
the 14.7 MeV data.
Node
Settings
Display
NEA / Incident neutron data
EXFOR / Cross sections / Ni58 / (,A)26-FE-55
20721.031
T I
DATA
P
21958.002
22465.003
22465.006
31481.005
31507.004
20721.031
points :
1
8 columns
Independent variables
EN
EN-RSL
Dependent variables
DATA
DATA-ERR
Other
MONIT1
MONIT1-ERR
MONIT2
MONIT2-ERR
Additional EXFOR
Additional ENDF

EXFOR


JANIS 4.0 - OECD Nuclear En
JANIS
JANIS - Renderer
EXFOR: Experimental Nuclear
https://www-nds.iaea.org/exfor/exfor.htm
Search
Help » Manual PDF | Lexfor | NNDC-Help | Output | Plot+ | R33
Databases » ENDF | CINDA | IBANDL
CD-ROM » EXFOR-CINDA | CD-Catalog
NNDC
NRDC
Experimental Nuclear Reaction Data (EXFOR)
Database Version of 2017-07-03
Software Version of 2017-07-03
News
2016/12 New.Web-ZVView plots: affine transformations (PS/EPS) [how-to], distortion picture using 2D-calibration [how-to]
2016/11 Plotting without grouping by reaction-codes (+ calculating CS ratios between diff. datasets on the fly) [example]
2016/11 Plotting cross section coded with SF8=DAM (CS divided by atomic mass of target) [example] #Adv.plot using C5
2016/11 Recalculation of angular distributions to inverse kinematics (when converting EXFOR→R33) [example]
[History]
The EXFOR library contains an extensive compilation of experimental nuclear reaction data. Neutron reactions have been compiled systematically since the discovery of the neutron, while charged particle and photon reactions have been covered less extensively.
The library contains data from 21798 experiments (see statistics and recent updates).
EXFOR Reference Paper: Nucl. Data Sheets 120(2014)272
EXFOR Mirror-sites
Search:
Go
Examples of requests: 1 2 3 4 5 6 7...
1 Cross section σ(E) /updates/ More examples...
Request
Submit
Reset
Help
Target
Reaction
Quantity
Product
Energy from
to
eV
Author(s)
Publication year
Last modified
Accession #
Extended
Keywords
Expert
Submit
Reset
Go to: [upload your data]
Options
Exclude superseded data
No reaction combinations (ratios,..)
Exclude evaluated data
Enhanced search of Products
Retrieve listing only
Disable Prompt-Help
Sort by: reaction publication
View: basic extended
Plotting. See also: [video-guide]
Ranges (Z,A)
Reaction Sub-Fields
Feedback and User's Input
Clone Request:
CINDA
ENDF
Note:
- all criteria are optional (selected by checking ✓)
- selected criteria are combined for search with logical AND
- criteria separated in a field by ";" are combined with logical OR

EXFOR


JANIS 4.0 - OECD Nuclear En
JANIS
JANIS - Renderer
EXFOR: Experimental Nuclear
https://www-nds.iaea.org/exfor/exfor.htm
Search
Help » Manual PDF | Lexfor | NNDC-Help | Output | Plot+ | R33 Databases » ENDF | CINDA | IBANDL CD-ROM » EXFOR-CINDA | CD-Catalog
NNDC
NRDC
Experimental Nuclear Reaction Data (EXFOR)
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Search: Go ?
Examples of requests: 1 2 3 4 5 6 7...
1 Cross section σ(E) /updates/ More examples...
Request Submit Reset Help
Target Ni-58
Reaction n,a
Quantity CS
Product
Energy from to eV
Author(s)
Publication year
Last modified
Accession #
Extended
Keywords
Expert
Submit Reset
Go to: [upload your data]
Options
Exclude superseded data
No reaction combinations (ratios,..)
Exclude evaluated data
Enhanced search of Products
Retrieve listing only
Disable Prompt-Help
Sort by: reaction publication
View: basic extended
Plotting. See also: [video-guide]
Ranges (Z,A)
Reaction Sub-Fields
Feedback and User's Input
Clone Request:
CINDA ENDF
Note:
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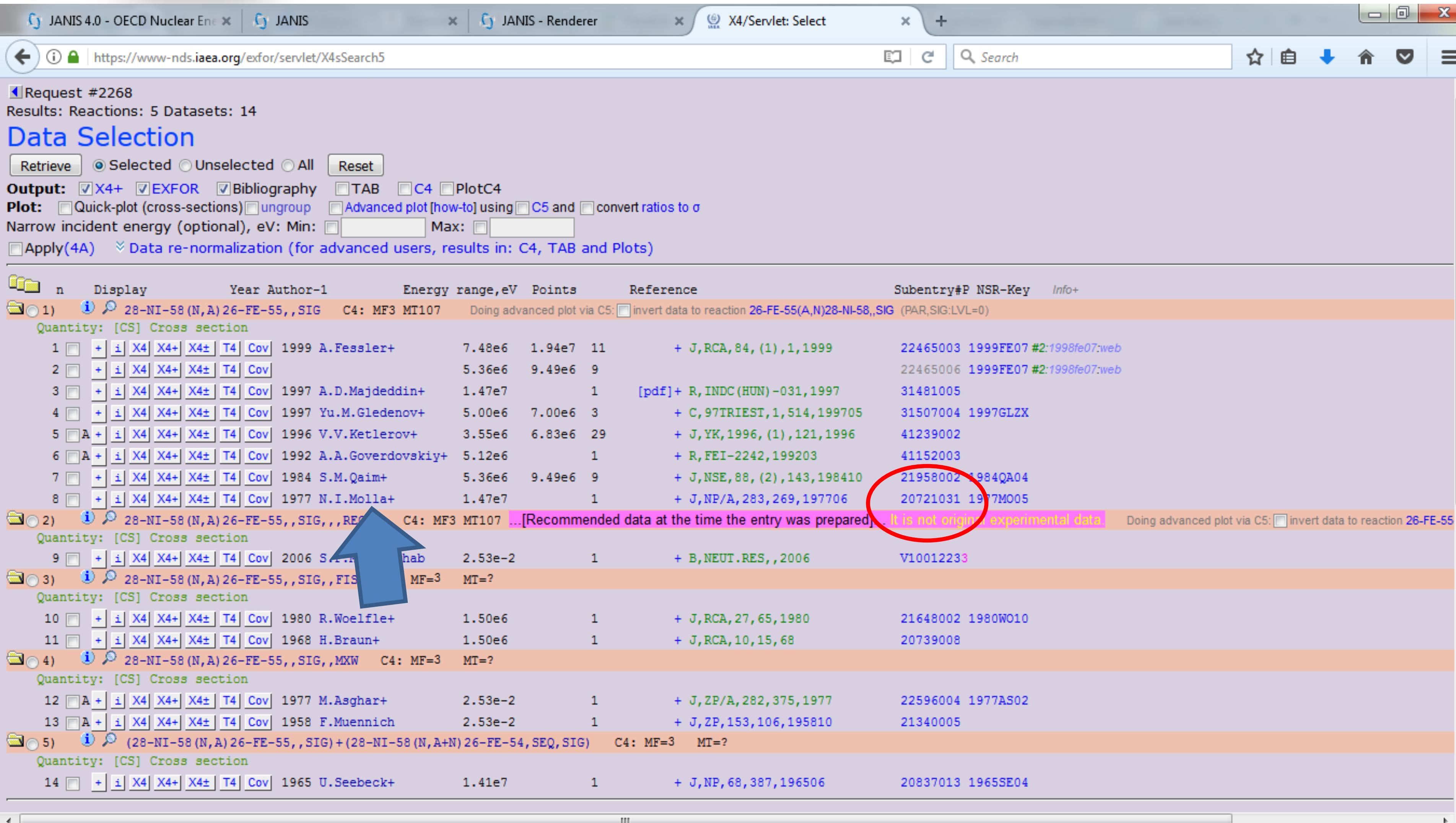
EXFOR



JANIS 4.0 - OECD Nuclear En | JANIS | JANIS - Renderer | X4/Servlet: Select

https://www-nds.iaea.org/exfor/servlet/X4sSearch5

Request #2268
Results: Reactions: 5 Datasets: 14

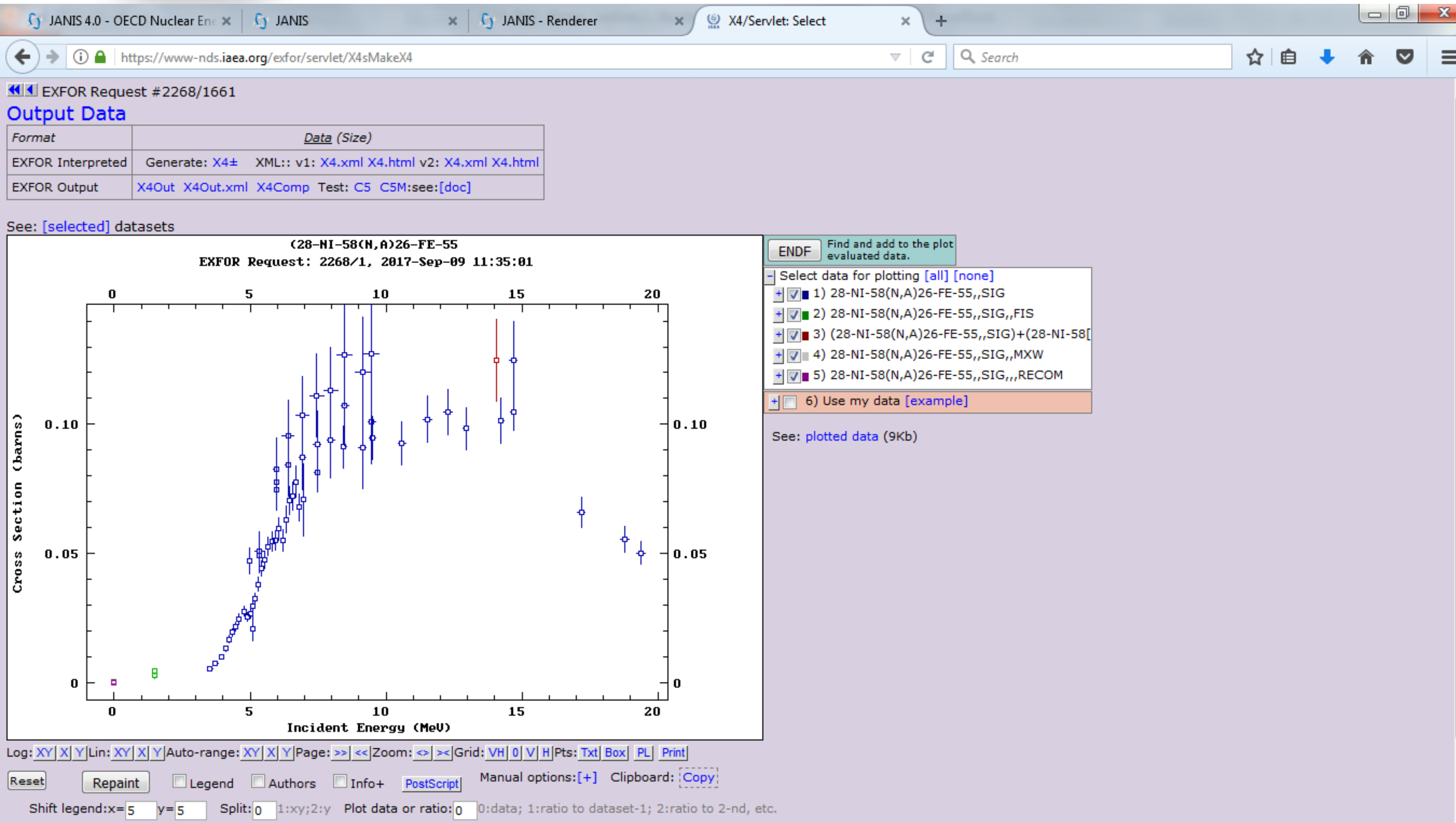
Data Selection

Retrieve | Selected | Unselected | All | Reset

Output: X4+ EXFOR Bibliography TAB C4 PlotC4
Plot: Quick-plot (cross-sections) ungroup Advanced plot [how-to] using C5 and convert ratios to σ
Narrow incident energy (optional), eV: Min: Max:
Apply(4A) Data re-normalization (for advanced users, results in: C4, TAB and Plots)

n	Display	Year	Author-1	Energy range,eV		Points	Reference	Subentry#P	NSR-Key	Info+
1)	28-NI-58(N,A)26-FE-55,,SIG C4: MF3 MT107						Doing advanced plot via C5: invert data to reaction 26-FE-55(A,N)28-NI-58,,SIG	(PAR,SIG:LVL=0)		
	Quantity: [CS] Cross section									
1	+ i X4 X4+ X4± T4 Cov	1999	A.Fessler+	7.48e6	1.94e7	11	+ J,RCA,84,(1),1,1999	22465003	1999FE07	#2:1998fe07:web
2	+ i X4 X4+ X4± T4 Cov			5.36e6	9.49e6	9		22465006	1999FE07	#2:1998fe07:web
3	+ i X4 X4+ X4± T4 Cov	1997	A.D.Majdeddin+	1.47e7		1	[pdf]+ R,INDC(HUN)-031,1997	31481005		
4	+ i X4 X4+ X4± T4 Cov	1997	Yu.M.Gledenov+	5.00e6	7.00e6	3	+ C,97TRIEST,1,514,199705	31507004	1997GLZX	
5	A + i X4 X4+ X4± T4 Cov	1996	V.V.Ketlerov+	3.55e6	6.83e6	29	+ J,YK,1996,(1),121,1996	41239002		
6	A + i X4 X4+ X4± T4 Cov	1992	A.A.Goverdovskiy+	5.12e6		1	+ R,FEI-2242,199203	41152003		
7	+ i X4 X4+ X4± T4 Cov	1984	S.M.Qaim+	5.36e6	9.49e6	9	+ J,NSE,88,(2),143,198410	21958002	1984QA04	
8	+ i X4 X4+ X4± T4 Cov	1977	N.I.Molla+	1.47e7		1	+ J,NP/A,283,269,197706	20721031	1977MO05	
2)	28-NI-58(N,A)26-FE-55,,SIG,,,REC C4: MF3 MT107						...[Recommended data at the time the entry was prepared]... It is not original experimental data. Doing advanced plot via C5: invert data to reaction 26-FE-55			
	Quantity: [CS] Cross section									
9	+ i X4 X4+ X4± T4 Cov	2006	S.F.Mughabghab	2.53e-2		1	+ B,NEUT.RES,,2006	V10012233		
3)	28-NI-58(N,A)26-FE-55,,SIG,,FIS C4: MF=3 MT=?									
	Quantity: [CS] Cross section									
10	+ i X4 X4+ X4± T4 Cov	1980	R.Woelfle+	1.50e6		1	+ J,RCA,27,65,1980	21648002	1980WO10	
11	+ i X4 X4+ X4± T4 Cov	1968	H.Braun+	1.50e6		1	+ J,RCA,10,15,68	20739008		
4)	28-NI-58(N,A)26-FE-55,,SIG,,MXW C4: MF=3 MT=?									
	Quantity: [CS] Cross section									
12	A + i X4 X4+ X4± T4 Cov	1977	M.Asghar+	2.53e-2		1	+ J,ZP/A,282,375,1977	22596004	1977AS02	
13	A + i X4 X4+ X4± T4 Cov	1958	F.Muennich	2.53e-2		1	+ J,ZP,153,106,195810	21340005		
5)	(28-NI-58(N,A)26-FE-55,,SIG)+(28-NI-58(N,A+N)26-FE-54,SEQ,SIG) C4: MF=3 MT=?									
	Quantity: [CS] Cross section									
14	+ i X4 X4+ X4± T4 Cov	1965	U.Seebeck+	1.41e7		1	+ J,NP,68,387,196506	20837013	1965SE04	

EXFOR


JANIS 4.0 - OECD Nuclear En
JANIS
JANIS - Renderer
X4/Servlet: Select
https://www-nds.iaea.org/exfor/servlet/X4sMakeX4
EXFOR Request #2268/1661
Output Data
Format | Data (Size)
EXFOR Interpreted | Generate: X4± XML:: v1: X4.xml X4.html v2: X4.xml X4.html
EXFOR Output | X4Out X4Out.xml X4Comp Test: C5 C5M:see:[doc]
See: [selected] datasets
(28-NI-58(N,A)26-FE-55
EXFOR Request: 2268/1, 2017-Sep-09 11:35:01
Cross Section (barns)
Incident Energy (MeV)
ENDF
Find and add to the plot evaluated data.
Select data for plotting [all] [none]
1) 28-NI-58(N,A)26-FE-55,,SIG
2) 28-NI-58(N,A)26-FE-55,,SIG,,FIS
3) (28-NI-58(N,A)26-FE-55,,SIG)+(28-NI-58[
4) 28-NI-58(N,A)26-FE-55,,SIG,,MXW
5) 28-NI-58(N,A)26-FE-55,,SIG,,,RECOM
6) Use my data [example]
See: plotted data (9Kb)
Log: XY X Y Lin: XY X Y Auto-range: XY X Y Page: >> << Zoom: <> >< Grid: VH 0 V H Pts: Txt Box PL Print
Reset Repaint Legend Authors Info+ PostScript Manual options:[+] Clipboard: Copy
Shift legend:x= 5 y= 5 Split: 0 1:xy;2:y Plot data or ratio: 0 0:data; 1:ratio to dataset-1; 2:ratio to 2-nd, etc.

Conclusion

Good starting point:

Do not only look at the data points but read up on

how and ***where*** previous measurements for the reaction you want to study were performed.

You may also want to take a look at similar reactions.

What challenges did the experimentalists face?

What worked well?

How well?

What did not work?

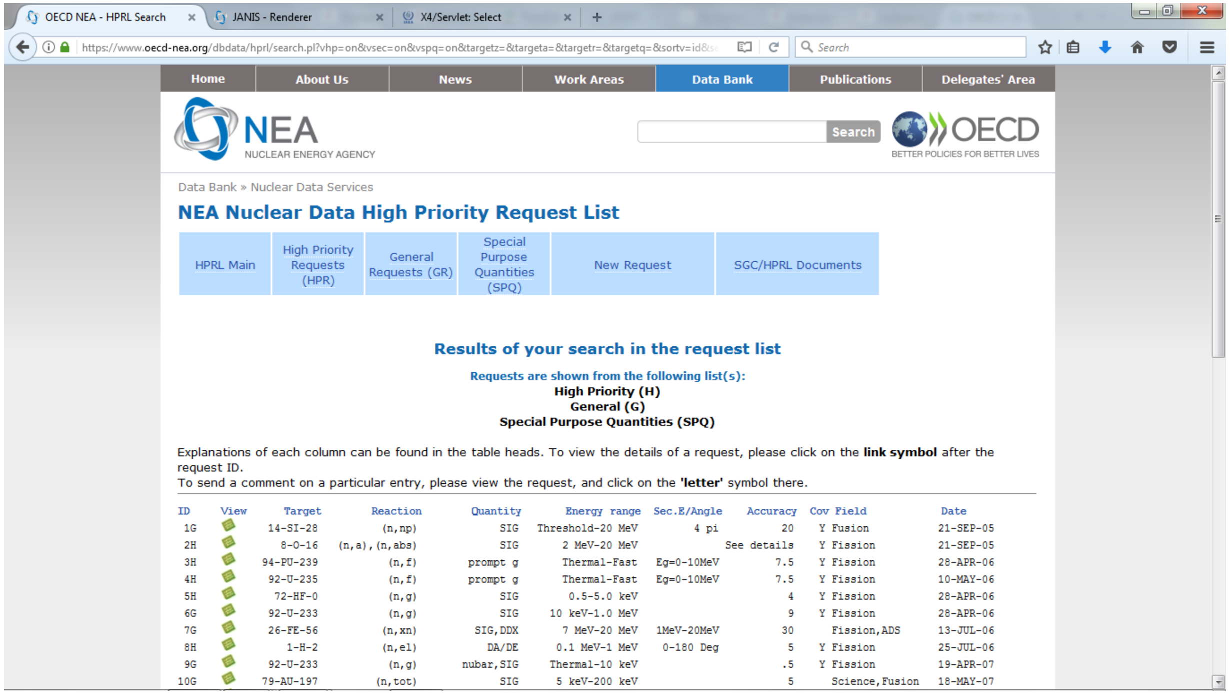
Outline

- Nuclear data measurements is about fulfilling needs …
- Which data?
- How to select? And where to start?
  - User needs, HPRL, JANIS, EXFOR …
- An example

A test case

Let's walk through a possible experiment

Starting point: some data needs, e.g., from the HPRL:


Home | About Us | News | Work Areas | Data Bank | Publications | Delegates' Area

NEA NUCLEAR ENERGY AGENCY

OECD BETTER POLICIES FOR BETTER LIVES

Data Bank » Nuclear Data Services

NEA Nuclear Data High Priority Request List

HPRL Main | High Priority Requests (HPR) | General Requests (GR) | Special Purpose Quantities (SPQ) | New Request | SGC/HPRL Documents

Results of your search in the request list

Requests are shown from the following list(s):
High Priority (H)
General (G)
Special Purpose Quantities (SPQ)

Explanations of each column can be found in the table heads. To view the details of a request, please click on the **link symbol** after the request ID.
To send a comment on a particular entry, please view the request, and click on the **'letter'** symbol there.

ID	View	Target	Reaction	Quantity	Energy range	Sec.E/Angle	Accuracy	Cov	Field	Date
1G		14-SI-28	(n,np)	SIG	Threshold-20 MeV	4 pi	20	Y	Fusion	21-SEP-05
2H		8-O-16	(n,a),(n,abs)	SIG	2 MeV-20 MeV		See details	Y	Fission	21-SEP-05
3H		94-PU-239	(n,f)	prompt g	Thermal-Fast	Eg=0-10MeV	7.5	Y	Fission	28-APR-06
4H		92-U-235	(n,f)	prompt g	Thermal-Fast	Eg=0-10MeV	7.5	Y	Fission	10-MAY-06
5H		72-HF-0	(n,g)	SIG	0.5-5.0 keV		4	Y	Fission	28-APR-06
6G		92-U-233	(n,g)	SIG	10 keV-1.0 MeV		9	Y	Fission	28-APR-06
7G		26-FE-56	(n,xn)	SIG,DDX	7 MeV-20 MeV	1MeV-20MeV	30		Fission,ADS	13-JUL-06
8H		1-H-2	(n,el)	DA/DE	0.1 MeV-1 MeV	0-180 Deg	5	Y	Fission	25-JUL-06
9G		92-U-233	(n,g)	nubar,SIG	Thermal-10 keV		.5	Y	Fission	19-APR-07
10G		79-AU-197	(n,tot)	SIG	5 keV-200 keV		5		Science,Fusion	18-MAY-07

LCP from ^{39}K for fusion app.

The latest request is from May 2017 and concerns measurement of

^{39}K(n,p) and ^{39}K(n,np) in the energy range between 10 and 20 MeV.

39H	94-PU-242	(n,f)	SIG	200 keV-20 MeV		See details	Y Fission	15-SEP-08
40H	14-SI-28	(n,inl)	SIG	1.4 MeV-6 MeV		See details	Y Fission	15-SEP-08
41H	82-PB-206	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y Fission	15-SEP-08
42H	82-PB-207	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y Fission	15-SEP-08
43H	1-H-1	(n,el)	SIG,DA	10 MeV-20 MeV	4 pi	1-2	Y Standard	29-APR-11
44H	93-NP-237	(n,f)	SIG,DE	200 keV-20 MeV			Y Fission	11-MAY-15
45H	19-K-39	(n,p),(n,np)	SIG	10 MeV-20 MeV		10	Y Fusion	17-MAY-17

Number of requests found: 38 (out of a total of 38 requests).

Download consolidated output report

Request ID	45		Status of the request	High Priority request	
Target	Reaction and process	Incident Energy	Secondary energy or angle	Target uncertainty	Covariance
19-K-39	(n,p),(n,np) SIG	10 MeV-20 MeV		10	Y
Field	Subfield	Date Request created	Date Request accepted	Ongoing action	
Fusion		17-MAY-17	11-JUL-17		

Send a comment on this request to NEA.

Requester: Dr Stanislav SIMAKOV at KARLSRUHE, GER
Email: stanislav.simakov@kit.edu

Project (context): IFMIF and DONES material test facilities, and fusion power plants

Impact:
The 39K(n,p) reaction produces 39Ar with decay half-life of 269 years and makes the dominant contribution to the long-lived radioactive inventories in NaK. The latter is considered as a coolant of specimens in the accelerator driven irradiation facilities that are designed now for the fusion material testing (IFMIF [1], DONES [2] ...). Together with the competing reaction 39K(n,np)38Ar they also determine the total amount of Argon gas which impact on the thermal and mechanical properties of sealed specimens containers [3]. The current poor knowledge of these two reactions questions whether NaK could be used in the IFMIF and DONES design. Additionally, since potassium is present in cement and concrete, the 39K(n,p)39Ar reaction impacts on the long-term radioprotection and shielding issues in IFMIF/DONES testing vaults and future fusion power plants.

Accuracy:
The continuous Argon gas leakage through cracks in the welding of sealed containers or their accidental rupture is a complex process. Because of this complexity, the sensitivity analyses quantifying the required accuracy of the cross sections have never been done. However, considering the potentially high impact and the poor knowledge of these cross sections, a request for 10% accuracy is a reasonable requirement that will be practically achievable by utilizing the current techniques. This requirement is supported by the fusion and general nuclear data users.

Justification document:

At 14 MeV neutron energy 3 measurements by proton spectroscopy and activation [4-6] reported 3 times larger value for 39K(n,p)39Ar reaction cross section than measurement by AMS [7]. For competing reaction 39K(n,np)38Ar the situation is vice versa. See Ref. [3] for more information.

The main evaluated libraries are similarly discrepant depending on which experiment they follow.

The new measurement is needed first at 14 MeV to resolve this contradiction.

References

Data Hi × JANIS - Renderer × X4/Servlet: Select × +

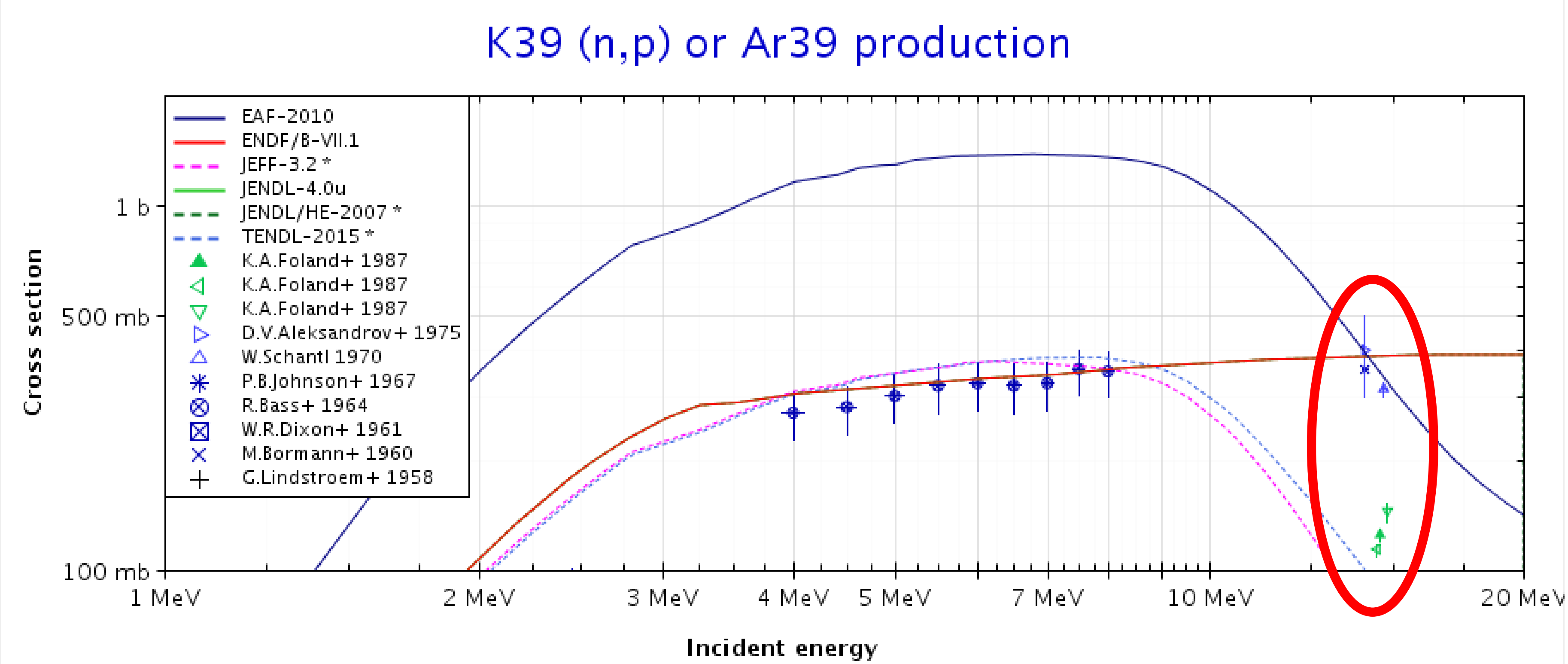
g/janisweb/book/neutrons/K39/MT103/renderer/319

ar Science and Engineering 95 (1987) 128.

<< 18-Ar-40 19-K-39 19-K-40 >>

<< MT102 (n,γ) MT103 (n,p) or MT5 (Ar39 production) MT105 (n,t) >>

Home | Computed data, 40433.011, 13109.002, 11608.003, 21...



Node	Settings	Display
NEA / Incident neutron data		
EXFOR / Cross sections / K39 / (,P)18-AR-39		
EAF-2010 / Cross sections / K39 / MT=103 : (z,p) / Cross section		P T
ENDF/B-VII.1 / Cross sections / K39 / MT=103 : (z,p) / Cross section		P T
JEFF-3.2 / Energy-angle distributions / K39 / MT=5 : (z,anything) / MF3+MF6MT5		P T
JENDL-4.0u / Cross sections / K39 / MT=103 : (z,p) / Cross section		P T
JENDL/HE-2007 / Energy-angle distributions / K39 / MT=5 : (z,anything) / MF3+MF6MT5		P T

rch | JANIS - Renderer | X4/Servlet: Select

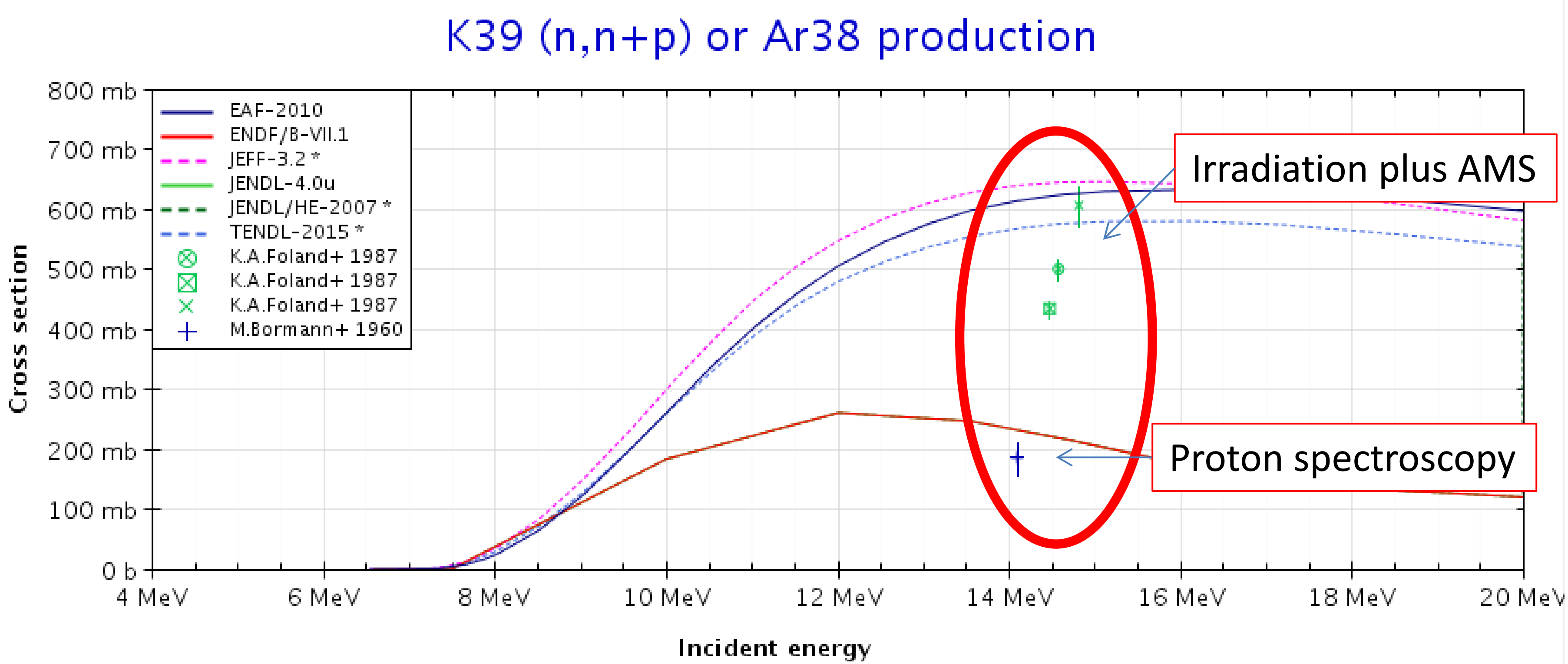
rg/janisweb/book/neutrons/K39/MT28/renderer/319

periodic table

<< 18-Ar-40 | **19-K-39** | 20-Ca-40 >>

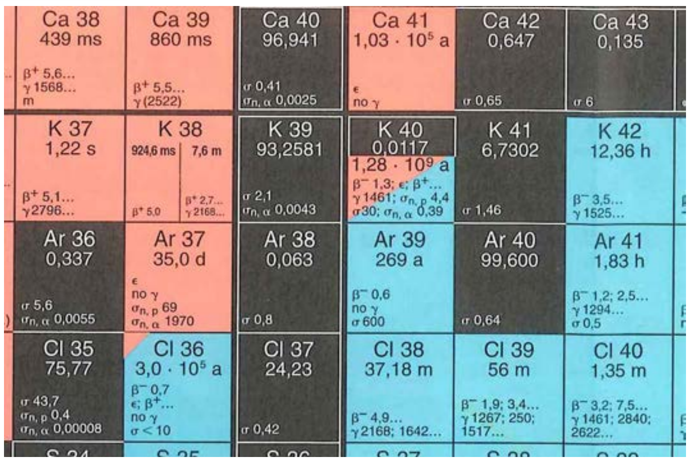
<< MT22 (n,n+α) | **MT28 (n,n+p) or MT5 (Ar38 production)** | MT102 (n,γ) >>

Home | Computed data, 21668.010, 13109.005, 13109.006, 13...



Node	Settings	Display
NEA / Incident neutron data		
EXFOR / Cross sections / K39 / (,N+P)18-AR-38		
EAF-2010 / Cross sections / K39 / MT=28 : (z,n+p) / Cross section		P T
ENDF/B-VII.1 / Cross sections / K39 / MT=28 : (z,n+p) / Cross section		P T
JEFF-3.2 / Energy-angle distributions / K39 / MT=5 : (z,anything) / MF3+MF6MT5		P T
JENDL-4.0u / Cross sections / K39 / MT=28 : (z,n+p) / Cross section		P T
JENDL/HE-2007 / Energy-angle distributions / K39 / MT=5 : (z,anything) / MF3+MF6MT5		P T

Look at some basics first

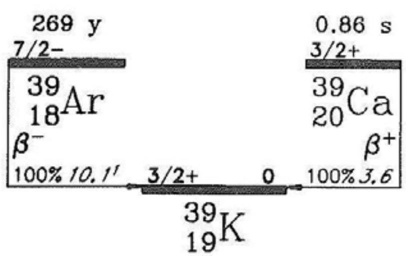


Isotopic compostion of ^{nat}K:

^{39}K	93.26%
^{40}K	0.01%
^{40}K	6.73%

Reaction products:

^{38}Ar	stable
^{39}Ar	β^-



β^--decay goes to g.s.

γ-spectroscopy not possible ☹

(Note: for ^{41}K(n,p), γ-spectroscopy would be an option)

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Options?

- Either use proton spectroscopy (e.g. with active detector),

200 M. BORMANN, H. JEREMIE, G. ANDERSSON-LINDSTRÖM, H. NEUERT UND H. POLLEHN

Über die Wirkungsquerschnitte einiger von 14 MeV-Neutronen in den Szintillationskristallen NaJ(Tl), KJ(Tl), CsJ(Tl) und $Li^6J(Eu)$ ausgelösten Kernreaktionen*

Von M. BORMANN, H. JEREMIE **, G. ANDERSSON-LINDSTRÖM, H. NEUERT und H. POLLEHN

Aus dem Physikalischen Staatsinstitut, I. Institut für Experimentalphysik, Hamburg

(Z. Naturforschg. **15 a,** 200—210 [1960]; eingegangen am 20. Januar 1960)

http://zfn.mpdl.mpg.de/data/Reihe_A/15/ZNA-1960-15a-0200.pdf

- or use mass measurement of products

The Production of ^{38}Ar and ^{39}Ar by 14-MeV Neutrons on ^{39}K

K. A. Foland, R. J. Borg, M. G. Mustafa

Nuclear Science and Engineering / Volume 95 / Number 2 / February 1987 / Pages 128-134
Technical Paper / dx.doi.org/10.13182/NSE87-A20423

Target?

Tricky:

- Potassium is a highly reactive metal
- Either treat under vacuum or inert gas or
- Use a composite (which needs background subtraction)

For the sake of this discussion: let's assume we found a way to handle thin K sheets (e.g., sealed between mylar foils) as a target …

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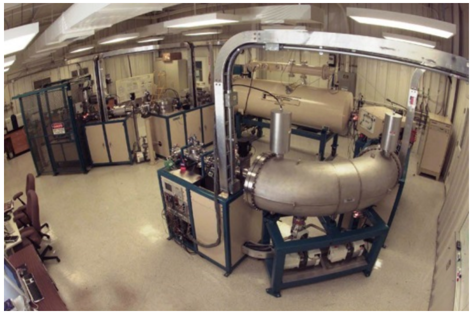
Passive or active?



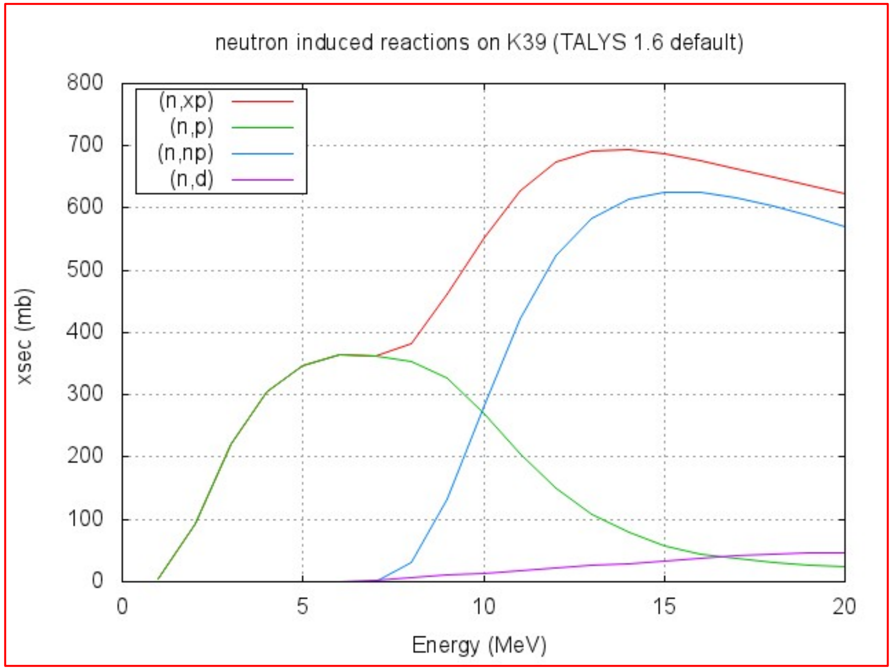
- Out-of-beam measurement
  - activation technique; e.g. irradiation plus AMS
  - needs either mono-energetic beam (e.g., DT), or QMN + unfolding/low-E-tail subtraction methods
  - Pro: Measures product (independent of reaction channel)
  - Con: Limited number of available beam energies

- In-beam measurement
  - neutron beam plus online detection
  - Pro: measurements at many incoming energies possible
  - Con: possible ambiguity on reaction product (e.g., (n,xp) measurement)

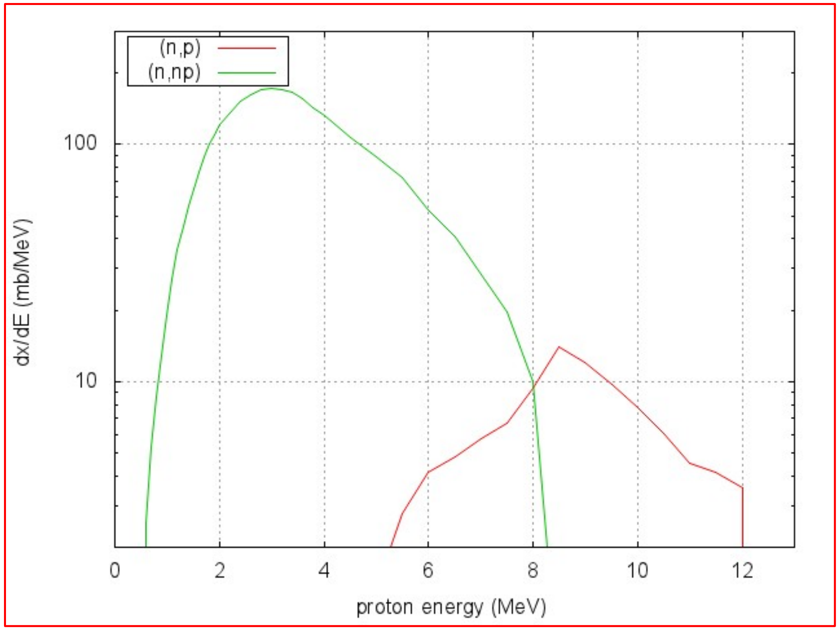
Let's say we opt for proton detection

- Method?
  - Active target (target = part of detector)
    - Pro: 4π coverage
    - Con: careful response analysis necessary
  - Target + Telescope (ΔE-E)
    - Pro: PID, energy spectra, angular distributions
    - Con: small $\Delta\Omega$ coverage
- Beam?
  - DT source: one mono-energetic beam
  - QMN beams (Li(p,n)): several beams but low-E tail
  - White beam: "all in one"

One problem though …



What we would measure is (n,xp). According to TALYS this xs is, in the 10-20 MeV region, heavily dominated by (n,np).



Possible way out?
Study the energy of the emitted proton:

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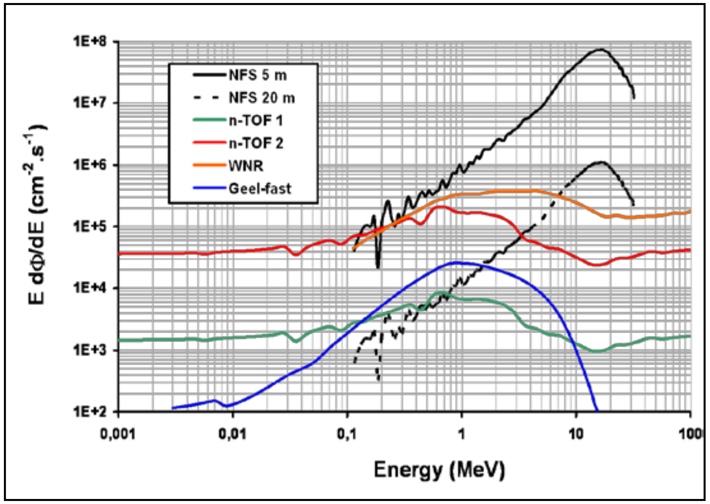
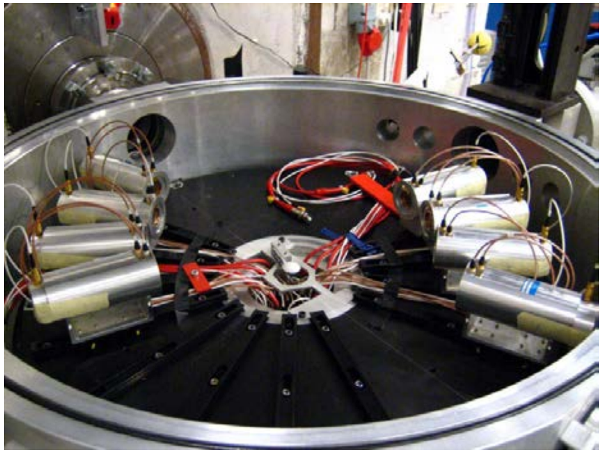
Anyway, we go ahead and …

… decide that we want to use a **white neutron beam** with good intensity in the interesting energy range (NFS) and that we use a setup like Medley:





The HRPL asks for an uncertainty for the measured cross section below 10%. Typically systematic uncertainties dominate (normally larger than 5%) so we need to go for a **statistical uncertainty** of, say, **better than 1%** (10,000 events).

Question: how much beam time would we need?

Reaction rate estimation

$$\boxed{R = \sigma_{(n,p)} \cdot \Phi_{beam} \cdot N_{target}}$$

Reaction rate per unit time and energy bin

1/s/MeV

Cross section

$1/cm^2$

Beam flux per unit time, unit area and energy bin

$1/cm^2/s/MeV$

Number of target nuclei within the beam

Let's use 1 MeV bins

Reaction rate estimation

$$\boxed{R = \sigma_{(n,p)} \cdot \Phi_{beam} \cdot N_{target}}$$

The cross section is roughly 200 mb:

200 mb = 200 · 10^{-3} · 10^{-24} cm^2 = **2 · 10^{-25} cm^2**

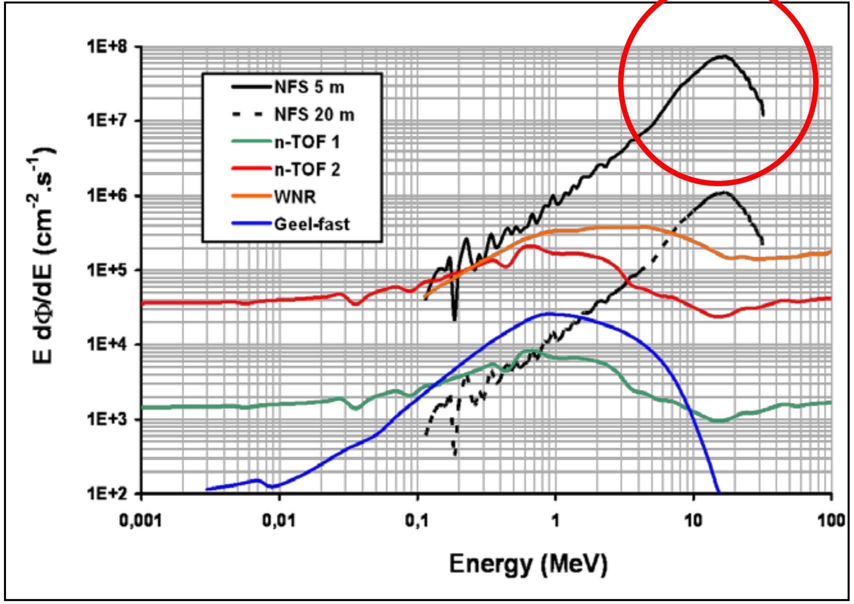
Reaction rate estimation

$$R = \sigma_{(n,p)} \cdot \Phi_{beam} \cdot N_{target}$$

NFS flux at 5 m according to the figure:

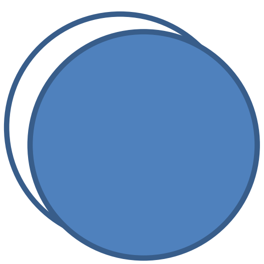
E_n [MeV]	$E\, d\Phi/dE$ [$cm^{-2}\, s^{-1}$]	$d\Phi/dE$ [$cm^{-2}\, s^{-1}\, MeV^{-1}$]
5	$1 \cdot 10^7$	$2 \cdot 10^6$
10	$4 \cdot 10^7$	$3 \cdot 10^6$
15	$7 \cdot 10^7$	$5 \cdot 10^6$
20	$5 \cdot 10^7$	$2.5 \cdot 10^6$

Let as use an average of $\mathbf{3 \cdot 10^6\, cm^{-2}\, s^{-1}\, MeV^{-1}}$



Reaction rate estimation

$$\boxed{R = \sigma_{(n,p)} \cdot \Phi_{beam} \cdot N_{target}}$$



Target:
assume a disc of metallic potassium (yes, it is tricky …) with

- diameter 3 cm, i.e., A_{target} =
- thickness t = 100 µm, and
- density ρ = 0.89 g/cm^3 (areal density is then 8.9 mg/cm^2).

$$N_{target} = \rho \cdot t \cdot A_{target} \cdot \frac{N_A}{M_a} \approx 10^{21}$$

Reaction rate estimation

$$\boxed{R = \sigma_{(n,p)} \cdot \Phi_{beam} \cdot N_{target}}$$

Using

$\sigma_{(n,p)}$ = 2 · 10^{-25} cm^{2}

Φ_{beam} = 3 · 10^{6} cm^{-2} s^{-1} MeV^{-1}

N_{target} = 1 · 10^{21}

we get R = 600 s^{-1} MeV^{-1}

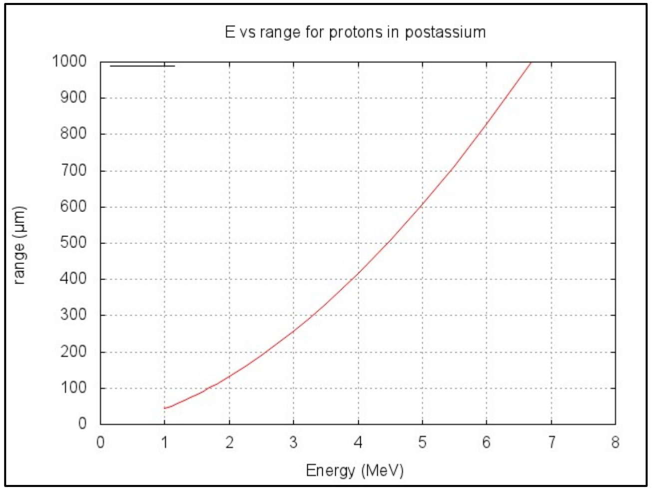
Assuming further we have **an arrangement of 10 detector telescopes** with Si detectors (100% efficiency for protons) with an opening are of **450 mm^2 each** and placed at a **distance of 10 cm**, we **cover about 3.6% of 4π**.

This finally gives that we register 20 events per second and would need (only) 500 seconds to collect 10,000 events.

What more …

… do we need to consider?

We need to correct for energy and particle losses in the target. But 100 µm thickness seems quite ok:



Calculated with SRIM; see srim.org

Furthermore: what we would measure with a setup of telescopes placed at different angles is in fact **$d\sigma/d\Omega(\Theta)$**.

To get σ we need to **integrate over the scattering angle**, probably needing proper interpolation/extrapolation, i.e.,
a theoretical description of the **shape of the angular distribution**.

But we stop this discussion here for now.

In sum

We looked at the case of measuring the cross sections for
^{39}K(n,p) and ^{39}K(n,np) in the 10 to 20 MeV range.

Using a white neutron beam as in the future NFS facility and an arrangement of detector telescopes, we estimated that enough statistics could be collected within far less than one hour of beam time.

Main problems that one needs to solve:

- How to get a suitable target (potassium is chemically highly reactive). Maybe one can use a compound. But these would need advance background subtraction.
- How to distinguish between (n,p) and (n,np)? Following the present discussion we would measure (n,xp). However, with input from model calculations this might be good enough.
- Probably something else that we did not think of yet …